

Developing Remote Sensing Capabilities for Meter-Scale Sea Ice Properties

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LONG-TERM GOALS

The overarching goal of this work is to develop and validate remote sensing techniques to track sea ice physical properties of geophysical importance that occur below the pixel size of most global-coverage satellite assets.

OBJECTIVES

We will collect a dataset of high resolution satellite imagery and develop and field-validate methods for detecting melt pond area fraction, floe size distribution, and ice surface roughness from this imagery at a number of sites in the Arctic. The primary objective, in years 1 and 2, is to demonstrate the capability for operationally monitoring these variables. In the 3rd and 4th years of the project, these measurements will be scaled up to basin scale estimates, using both interpolation between observation sites and improved spectral mixing techniques to classify the fractional mixture of surface types within low resolution remote sensing imagery pixels, such as MODIS.

APPROACH

1. Task and acquire high resolution panchromatic and multispectral optical (e.g. Quickbird, Worldview, National Assets) and synthetic aperture radar (TerraSAR-X, COSMO-SkyMed, or RADARSAT-2) images of regionally representative ~10x10km test areas (Yr 1–4)
2. Collect in situ measurements of target variables for validation of data products derived from high resolution satellite assets, using surface based observations and aerial photography at three readily accessible sites. (Yr 1–2)

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3. Develop and validate automated pixel classification algorithms to extract pond coverage, floe size distribution, and ice surface roughness from high resolution satellite assets, and use these algorithms to create data products at sample sites distributed around the Arctic. (Yr 1-2)
4. Further develop and validate algorithms to derive melt pond coverage and floe size distribution from lower resolution assets through techniques such as spectral mixing based on in situ spectral measurements. (Yr 2–4)
5. Rapidly disseminate all data products created, along with suitable metadata, and publish methodology developed. (Yr 1–4)

WORK COMPLETED

Imagery Acquisition

We have worked with a wide variety of partners to task and acquire imagery tracking approximately 40 fixed sites and 4-8 drifting sites throughout the Arctic. A map of the targeted locations can be seen in Figure 1. Collection frequency varies from every few days (National Assets) to about monthly (commercial optical imagery) and collections include commercial optical, commercial radar, and national technical means imagery. Acquisition has proven more challenging than anticipated at the time of proposal due to changes in the inter-agency agreements available for imagery acquisition, largely related to budget reductions. We have responded to reductions in CRREL's ability to independently task imagery acquisitions through the NGA by working with others, particularly Paul Morin at the Polar Geospatial Center, Hans Greber at the University of Florida, and Robert Graydon at Scitor, to increase the frequency and diversity of imagery collections.

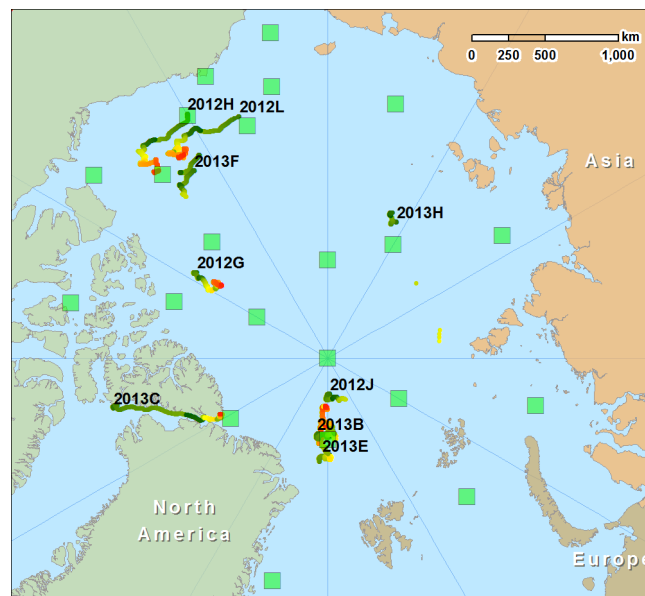


Figure 1. Drift tracks of buoys tracked from 6/26/13 to 9/26/13, color transitions from green to red over time. Green squares denote primary fixed sites, some additional fixed sites in the Chukchi and Beaufort that were targeted are not shown.

Commercial Optical imagery

We have tasked commercial panchromatic and multispectral optical imagery from Worldview 1 and 2 and Quickbird tracking both fixed locations and drifting sites. Fixed sites were submitted as a standing request for bi-weekly acquisition, while drifting sites were specifically tasked for collection every two weeks, adding new platforms as they became available (see table 1 for dates of tasking and CRREL Ice Mass Balance Buoys targeted). Imagery acquisitions designed to track the drifting buoys have been disappointing due to buoy drift and cloudiness limiting the number of useable, on target acquisitions, while fixed sites have generally performed better. Typical fixed sites have biweekly to monthly useable imagery, while drifting sites have less than 3 useable images for the season. We are working with our partners to reduce the delay between requesting imagery and its acquisition, as well as more frequently update tasking requests at the vendor in order to reduce buoy drift outside the target area, and exploring other techniques for submitting tasking requests to the vendors. Cloudiness was also a particular concern this year. The Arctic in general was quite cloudy compared to recent climatology, resulting in more limited opportunities for imagery acquisition than we'd experienced in recent years' pilot projects. Even accounting for the increased cloud cover, an excessive percentage of the imagery acquired over drifting sites was cloud covered, and the vendor did not delay acquisitions or repeat in better weather, suggesting issues with cloud detection. Delays between acquisition and posting did not allow for us to examine imagery in time to re-task. We are currently discussing the excessive cloudiness with the providers and seeking mechanisms to improve our ability to quality control and re-task as needed. We will also continue to seek opportunities to increase the temporal frequency of imagery acquisitions, particularly over lagrangian drifting sites, by coordinating our program demands with several others in need of similar imagery. We will use the fall and winter seasons to continue discussions with imagery providers, preparing ourselves to improve collection next year.

Table 1. Submission of 2013 tasking requirements for optical high-resolution commercial collections. Buoy names reflect the CRREL ice mass balance buoy targeted. See <http://imb.crrel.usace.army.mil/newdata.htm> for current locations. Note: Vendor ability to satisfy collection requirement dictated by several factors (e.g. cloud-cover percentage, collection competition, and satellite vendor issues collecting targets in close proximity to geographic North Pole).

	2012G	2012H	2012J	2012L	2012M	2013A	2013B	2013C	2013E	2013F	2013G	2013H
04/28/13	X	X	X	X	X	X	X		X			
05/13/13	X	X	X	X	X	X	X		X			
06/10/13	X	X	X	X	X	X	X	X	X			
07/02/13	X	X	X	X	X	X	X	X	X			
07/15/13	X	X	X	X	X		X	X	X			
07/30/13	X	X	X	X	X		X	X	X			
08/12/13	X	X	X	X	X		X	X	X			
08/27/13	X	X	X	X	X		X	X	X	X		
09/11/13	X	X	X	X			X	X	X	X	X	
09/23/13	X	X	X	X			X	X	X	X	X	X

Despite these challenges, we have been able to collect an imagery dataset that includes sample sites across most of the Arctic basin and spans a broad range of sea ice concentrations and melt pond coverage, both across space and time (Figure 3). The imagery is adequate for us to begin assessing the spatial and temporal variation of key variables at many of the sites we attempted to track, and we have built a sufficient library of imagery for us to test imagery processing techniques. The inclusion of these endmember states of sea ice concentration and melt pond coverage in the dataset is critical for developing accurate algorithms for classifying sea ice melt progression through the summer melt period and across the region.

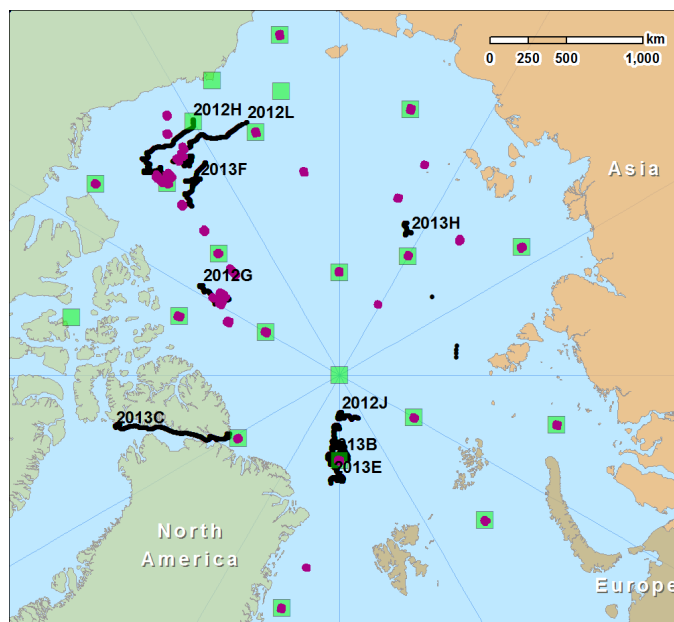


Figure 2. Locations of successful repeat acquisitions (purple). Fixed target sites (green) and drifting buoy tracks (black).

Declassified National Technical Means Imagery

We also communicated with members of the MEDEA team and Rob Graydon at Scitor to coordinate acquisition of imagery using National Technical Means satellites over at three of the CRREL IMB buoys, 2012 L, H, and G, in collaboration with Project N0001413MP20163, discussed below. Historically, the NTM imagery, released through the Global Fiducials program, has been highly successful at executing rapid repeats (every few days) of sites being tracked. The key benefit of the NTM imagery, therefore, is the ability to temporally infill multispectral imagery collected through the commercial vendors. We hope to use these panchromatic images to temporally infill the multispectral commercial collections. We are awaiting release of the derived products from these acquisitions, anticipated later this calendar year, but understand they were largely successful.

Commercial Radar imagery

Though radar imagery was not the central focus of this program, we are eager to leverage its capability to determine surface roughness, which is closely related to pond formation processes. We were able to conduct a time series of acquisitions with COSMO-SkyMed at our Beaufort Sea fixed site approximately every 10 days, beginning in early August.

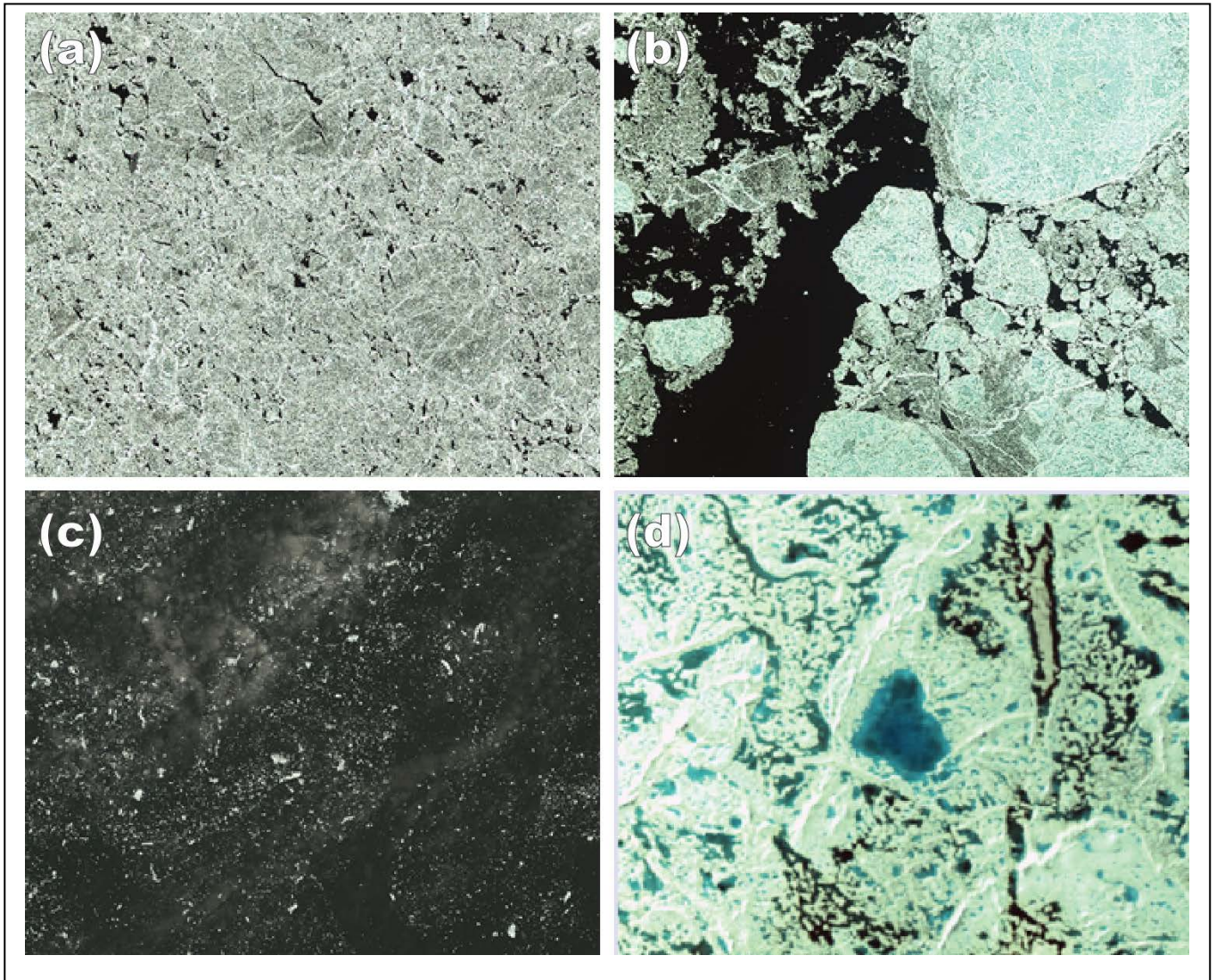


Figure 3. Examples of acquired WorldView-02 imagery in the Chukchi Sea, with particular emphasis on endmember sea ice states, including (a) high sea ice concentration (July 15, 2011); (b) medium sea ice concentration (July 13, 2011); and (c) low sea ice concentration (August 28, 2011). Imagery with varying levels of sea ice melt pond coverage has also been acquired (e.g., (d) imaged July 13, 2011).

Imagery Processing

We have begun developing our algorithms to segment and classify imagery, using both off the shelf software such as ENVI and implementing our own algorithms in Matlab. Our methods development has so far involved collating spectral albedo measurements from prior field work for different surface types and manually identifying pixels in imagery to create a library of surface spectral signatures. The library has some overlap in regions between very bright melt ponds and dirty sea ice, as well as between very dark melt ponds and open water. Even with spectral imagery, therefore, single pixel differentiation by spectral thresholding or band ratios has proven inadequate for image classification, as expected. We are currently testing the performance of several more sophisticated algorithms. Examples include a thresholding plus minimum distance classification which identifies pixels with band ratios in

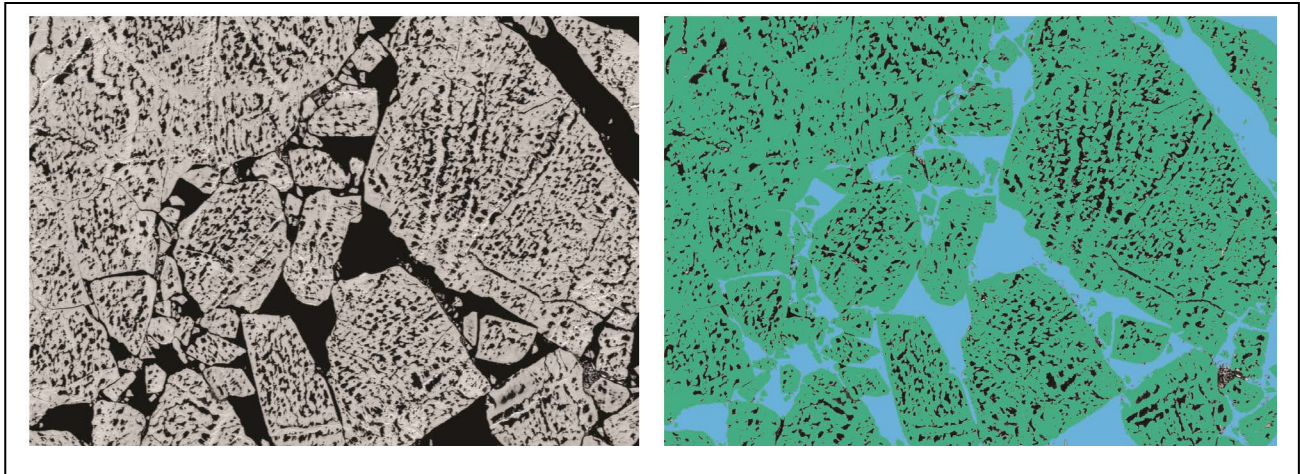


Figure 4. A sample segmentation and classification in progress. Pixels falling clearly into the center of threshold bounds have been classified as open water (blue) and bare ice (green), and melt ponds (black) have been classified. Boundary pixels that await classification can be seen around the ponds and in an area of broken brash ice in the lower right. A crack running into the large floe at right has been misclassified as pond rather than open water. When allowed to finish running, the remaining border pixels of ponds are mostly classified as ponds, over emphasizing pond cover. Field validation efforts will be necessary to refine how we handle mixed edge pixels.

the center of the expected spectral signature space, then clusters the remaining ambiguous pixels based on an iterative minimum distance technique (1) and K-means segmentation coupled with a maximum likelihood classification that assumes gaussian distribution of spectral signatures within each surface type and places each image segment into its classification of highest probability (2). The results of these preliminary efforts are very promising but also highlight challenges in establishing uniform unsupervised segmentation which we will address in the coming year. Partial cloud cover, surface shadowing, and streaking in some images preclude classification. In clear images under minimum distance schemes, long narrow cracks in floes are typically misclassified as melt ponds and mixed pixels at pond edges are excessively classified as ponded, while K-means segmentation often places segment boundaries at physically unimportant locations where image contrast or shadow changes, rather than at true boundaries. We have just begun exploring the use of shape parameters such as surface area to perimeter ratio and perimeter tortuosity to help differentiate between spectrally similar areas in multispectral imagery, an area where we will collaborate with project N0001413MP20102 in the coming year. Additionally we will further our development of object-based segmentation techniques to group segments based on similar spectral, texture, and shape properties and more standard image classification techniques, making particular use of the bounds provided by images of endmember states of sea ice and melt pond coverage.

Field Validation

We did not conduct any field programs this year, instead delaying them to next spring and taking the time to make proper preparations. The timing of our receipt of funding, combined with challenges arranging for imagery tasking made this the more reasonable approach. Had we pressed ahead with field programs this year it is likely that we would have had an incomplete accompanying set of satellite imagery, and we would not have been able to execute contracts to purchase important equipment prior to the program. In spring 2014 we will execute 2 field validation campaigns, collecting imagery in concert with detailed ice property observations using a UAV acquired for the project, terrestrial

LiDAR scans, and spectral albedo measurements. These validation campaigns will occur in the Chukchi Sea in collaboration with the USCG Healy, in the East Greenland Sea in collaboration with our partners at the Norwegian Polar Institute, and/or, potentially, at the U.S. Navy Ice camp, in collaboration with researchers at the Naval Research Laboratory.

RESULTS

We have:

- built networks with the imagery community, communicated our research needs and successfully captured a pan-Arctic satellite imagery dataset.
- executed contracts for purchase of key field equipment including a UAV for imagery acquisition, LiDAR software, and enhanced IDL processing tools.
- developed preliminary image classification and segmentation techniques for processing imagery for testing.
- arranged for multiple field opportunities in spring 2014 for technique validation

IMPACT/APPLICATIONS

The results of this study will include both a dataset of key meter-scale sea ice properties derived from our observation sites and the toolkit required to assess these properties in a uniform way from future imagery. This data and these techniques will enable synthesis activities seeking to explain the mechanisms and feedbacks governing ice loss in the Arctic.

RELATED PROJECTS

We are coordinating efforts and sharing data with a suite of three closely related projects:

N0001413MP20105: Propagation of Shortwave Radiation Through A Spatially Complex Melting Ice Cover – Lead PI Donald Perovich, USACE-CRREL

N0001413MP20102: Evolution of Melt Pond Geometry on Arctic Sea Ice – Lead PI Ken Golden, University of Utah

N0001413MP20163: The Seasonal Evolution of Sea Ice Floe Size Distribution" – Lead PI Jacqueline A. Richter-Menge, USACE-CRREL

Imagery acquisitions and processing efforts are being coordinated closely with PI Richter-Menge's efforts to use similar imagery to track the seasonal evolution of floe size distribution, and imagery both from our remote sensing classifications and our planned UAV flights will be shared with PI Golden's efforts to track the evolution of melt pond geometry. Finally, the results of our efforts will produce a surface type classification dataset necessary for Perovich's work to assess the interaction of shortwave radiation with the summer ice cover.

PUBLICATIONS

Polashenski, C., E. Deeb, C. Wood, J. Richter-Menge, D. Perovich, K. Frey, and M. Webster (2013), Remote Sensing of Meter-Scale Sea Ice Morphological Properties. Abstract submitted to International Glaciological Society Symposium on Sea Ice in a Changing Environment.

HONORS/AWARDS/PRIZES

Don Perovich, USACE-CRREL, AGU Fellowship Award, American Geophysical Union.